From the Lab to the Field - Development and Evaluation of Low-Cost Portable Spectrometers for Wood Quality Grading in Forest

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ABSTRACT

Portable spectroscopic instruments become an interesting alternative for in-field and on-line measurements. However, practical implementation of VIS-NIR portable sensors in the forest sector is still challenging due to harsh operating conditions and natural variability of wood itself. The VIS-NIR spectroscopy and hyperspectral imaging (HI) were used for development of an automatic grading system for logs. In addition to spectroscopic techniques, tree geometry, stress wave, cutting forces and data from harvester were merged to provide an overall quality class and define the optimal conversion path for each graded log. The grading system was validated during two demonstrations, in Italy and Austria, conducted in two different seasons (early summer and early winter). The final step was to integrate information regarding quality grading with a forest information system (FIS) database in order to provide additional input to refine stand growth and yield models for long-term silvicultural management.

INTRODUCTION

Grading of wood logs is an action used to determine a set of characteristics defining wood quality that are later used by forest resources managers, traders and manufacturers. Wood defects are abnormalities or irregularities of wood that may affect service life performance of products, such as reducing wood's strength, durability, appearance and, as a consequence, its economic value. Recently used methods rely on visual rating, which is subjective, operator-dependent, time-consuming, and not precise. Therefore, it is desired that grading should be conducted by means of automatic assessment to assure a faster, more reproducible and reliable way of quality sorting. The overall objective of this work was to use spectroscopic methods as an alternative to visual grading usually performed while assessing wood quality. NIR spectroscopic sensors were tested in manual mode as well as installed on the timber processor head. The latest solution allowed an automatic grading of logs at the earliest stage during their production in the forest.

MATERIALS

Twenty-five wood discs of Norway spruce (*Picea abies* L. Karst), cut from trees of diameters between 100 and 400 mm, were collected in Forchtenstein (Burgenland, Austria) in spring 2015. Directly after sampling, all samples were wrapped in aluminium and plastic foil, then were frozen and stored at 21°C in order to avoid wood drying and/or biological degradation. Laboratory measurements of the defrosted samples were performed at the surface temperature of approximately 15°C, without any additional sample conditioning and surface preparation. The target set of researched logs contained several wood defects frequently present in naturally grown tress, such as resin pockets, compression wood, knots and decay.

Spectroscopy: Three portable spectrometers covering different spectral ranges were selected for testing. The commercially available sensor MicroNIR Pro 1700 produced by VIAVI (Santa Barbara, USA) was used for both laboratory and in-field measurements. The operating range was 950-1650nm with resolution of 6.2nm. In addition, Hamamatsu C12880MA and C11708MA (Hamamatsu City, Japan) micro-spectrometers, covering the ranges of 340 - 780 nm with the resolution of 20nm and 640 - 1050 nm with the resolution of 15nm, were identified as low-cost alternative instruments potentially useful for measuring experimental samples. Since both spectrometers did not include focusing optics and built-in illumination, the 60x Zoom Mini Phone Camera Lens Microscope Magnifier was installed in the front of the spectrometer and the second lens in front of the 12V illuminating bulb. The electronic system used for controlling both spectrometers was developed using Arduino UNO microcontrollers.

Analysis: Two alternative classification methods, PLS-DA (Partial Least Square Discriminant Analysis) and SVMC (Support Vector Machine Classifier) were used for the spectroscopic data post-processing. PLS_Toolbox 8.0 (Eigenvector Research, Manson, USA) and LabView 13 (National Instruments, Austin, USA) were used as software platforms for spectral data analysis and chemometric models generation. More than 1800 independent spectra were used for the models development, considering 66% of spectra used for calibration and 34% for independent data set validation.

RESULTS

Two prediction rules were tested within this research: prediction most probable and prediction strict. In case of the prediction most probable, the PLS-DA model was capable to fit well the MicroNIR spectral data, with a success rate of 91%. The low-cost prototype sensors were also capable to properly identify wood defects, even though the success rates were lower (58% and 74% for Hamamtsu VIS and NIR, respectively). In the case of SVM, the overall success rate of prediction was higher (99% for MicroNIR, 83% for Hamamatsu NIR and 86% for Hamamatsu VIS). Prediction strict provided less accurate discrimination; nevertheless, the results for SVM were satisfactory (92%, 59% and 72% for MicroNIR, Hamamatsu NIR and Hamamatsu VIS, respectively). The most problematic was the differentiation between knots and reaction wood. This was due to several physical-chemical similarities between both defects and also limited spatial resolution/accuracy of prototype spectrometers.

CONCLUSIONS

In this work, one commercially available and two self-constructed prototype instruments were tested with the purpose of discrimination of wood defects. The up-to-date results and experiences highlight the MicroNIR sensor as a superior technique for fast and automatic discrimination of wood deficiencies. An important drawback of this solution is its relatively high cost, especially when considering the use of an array of sensors for better spatially defined analysis in-field or on-line. The prototype low cost sensors, therefore, may be a good alternative, allowing further customization of technical solutions and, consequently, improvement of the system's performance.